

**Evidence for Old Stars in the
Red Low Surface Brightness Galaxies
UGC 6614 and F568-6**

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ABSTRACT

We present near-Infrared images of low surface brightness galaxies: H band images of UGC 6614 and F568-6 (Malin 2). The H band images show spiral structure so we are confident that we are seeing the galaxy disks as well as the central bulges. The optical-IR colors of these galaxies, $R - H = 2.2 \pm 0.2$, $B - H = 3.5 - 4.2$, are extremely red and are similar to those of many S0 and elliptical galaxies. This represents strong evidence for a component of old stars. Recent studies find that low surface brightness galaxies span a wide range of morphologies and colors. In this context UGC 6614 and F568-6 could be examples of low surface brightness galaxies which have undergone a past epoch of more vigorous star formation.

Subject headings: galaxies: stellar content — galaxies: spiral — galaxies: low surface brightness galaxies — galaxies: individual (UGC 6614, F568-6)

1. Introduction

Most low surface brightness galaxies (LSBGs) discovered in photographically based surveys are unusually blue despite the lack of significant ongoing star formation, with mean colors $B - V = 0.49 \pm 0.04$ (McGaugh 1994), and $B - V = 0.7 \pm 0.05$ for the large scale length sample of Sprayberry et al. (1995). Generally the stellar populations of LSBGs are metal poor ($Z \sim 1/3$ solar, McGaugh 1994, also van der Hulst et al. 1993 and Schombert et al. 1990). Because of their blue colors and low surface brightness they are expected to be difficult to detect in the near-IR. In fact few LSBGs have been observed in the near-IR, with perhaps the only examples presented in Knezek & Wroten 1994. For recent reviews on LSBGs see Impey et al. 1997 or Bothun et al. 1997.

However, in our recent work studying the spiral structure of the large scale length LSBGs UGC 6614, and F568-6 (otherwise known as Malin 2), (Quillen & Pickering 1997) we found that the disks of these galaxies probably contain significant stellar mass surface densities (greater than a few $\times 10^{10} M_{\odot}$) and so have processed into stars a gas mass greater than that now observed in H I. These galaxies also have quite red colors and high metallicities (near or greater than solar (Pickering & Impey 1997; McGaugh 1994) compared to most LSBGs suggesting an old stellar population which would have moderate mass-to-light ratios consistent with our mass estimates. This prompted us to consider the possibility that this postulated older stellar population component would be easily detectable in the near-IR.

In this paper we report detections of low surface brightness galaxies in the near-IR bands. We emphasize here that the two low surface brightness galaxies observed here were chosen precisely because of their red colors, high metallicities and prominent spiral arm morphology which makes them exceptional compared to many currently cataloged LSBGs but similar to normal high surface brightness galaxies. We note that recent studies

(Knezek 1993 and O’Neil et al. 1997b) have emphasized that LSBGs have a wide variety of morphological and color properties.

2. Observations

The H images were obtained on the 61” Telescope of Steward Observatory on Mt. Bigelow on 1997 Feb 22 and 23 with a 256×256 NICMOS3 infrared array with a spatial scale of 0.90 arcsec/pixel. Individual images were taken with an exposure time of 30 seconds alternating between object and sky. Total on source integration times were 45 minutes with equivalent time spent on the sky. Flat fields were constructed from median filtered sky frames. Images were aligned to the nearest pixel and combined to form the final images. The H band images were observed during photometric conditions and were calibrated on the CTIO/CIT system using standard stars listed by Carter & Meadows 1995.

The B and V images were obtained on the 61” Telescope of Steward Observatory on Mt. Bigelow on 1997 Apr. 8 with a 1kCCD binned 2×2 so the resulting spatial scale is 0.40 arcsec/pixel. Individual images were taken with an exposure time of 300 seconds and total integration times were 25 minutes in both bands. These images were observed during photometric conditions and were calibrated to the Johnson system using three standard fields from Landolt 1992. The R band images were taken from Pickering et al. 1997 and are also displayed in Quillen & Pickering 1997.

For UGC 6614, our values for $B - V$ which range between 1.0 and 0.5 at larger radius, agree within 0.05 mag with those of McGaugh & Bothun 1994. The R band surface brightness radial profile of UGC 6614 agrees within 0.2 mag with that of Knezek 1993 and that of de Blok et al. 1995.

3. Results

In Fig. 1 are displayed grayscale B , R and H images of the two galaxies. Spiral structure seen in the optical images is also clearly evident in the H band images. We therefore detect in H band emission from the disks of these galaxies, as well as emission from their bulges. For both galaxies the spiral structure is more well defined in the B band than in the red R or H bands so that the spiral features become smoother with increasing wavelength. In normal high surface brightness galaxies spiral arms are also typically sharper in the bluer bands and smoother in the near-IR or red bands. The dependence of morphology on wavelength is a result of absorption from dust and emission from bright young blue stars both which are more prominent in bluer bands and are concentrated in narrow features concentrated along the spiral arms (see for example Gonzalez & Graham 1996). It is likely that the same is true in the two low surface brightness galaxies observed here.

In Fig. 2 we show radial surface brightness profiles in all bands observed. We note that in UGC 6614 the ring at $r \sim 30''$ is more sharply defined in the bluer bands. The ring which is evident as a peak in the radial surface brightness profile in B band could be more accurately described as a plateau in H band.

Fig. 2 also plots the various colors as a function of radius for both galaxies. We note that colors in all bands are quite quite red, though the ring in UGC 6614 at $r \sim 30''$ is bluer than the surrounding disk. Both galaxies show evidence for a color gradient in the sense that they become bluer with increasing radius. This type of color gradient is also observed in normal or high surface brightness galaxies and is consistent with an age or/and metallicity gradient (e.g. de Jong 1996).

In Fig. 3 we show the colors of UGC 6614 and F568-6 in a color/color plot compared to those of other galaxies and clusters. The nucleus of both galaxies has red colors typical

of a normal galaxy bulge which is similar to that of many elliptical galaxies. The outer disk of both galaxies, with $B - V \sim 0.5$ and $B - H \sim 3.8$, has colors similar to some Sc nuclei and older LMC or SMC clusters. It is likely that at large radius the disks are either younger or/and less metal rich, as is true in normal galaxies (e.g. Frogel 1988; de Jong 1996). We see that a significant fraction of the stellar population in these two LSBGs cannot be from young and metal-poor stars because the colors are too red, both in the bulge and in the outermost disk points measured.

4. Discussion

In this paper we have presented B, V, R and H band images of two low surface brightness galaxies UGC 6614 and F568-6 (Malin 2). Because we see spiral structure in our H band images we are confident that we detect in H band emission from the disks of these galaxies, as well as emission from their bulges. Because of the blue colors of the majority of currently cataloged low surface brightness galaxies and their low surface brightnesses, they were expected to be undetectable in the near-IR. We were only able to detect UGC 6614 and F568-6 at H band because they are extremely red.

In fact we have found that these galaxies have extremely red optical to near-IR colors, with $R - H = 2.2 \pm 0.2$ and $B - H = 3.5 - 4.2$. We find that these colors are similar to those of many S0 and elliptical galaxies and so are strong evidence for the presence of an old stellar population. As noted in previous studies (Frogel 1985) the nuclei of many high surface brightness spiral (Sc) galaxies have similar red colors.

We find that the spiral arms of these two galaxies are more prominent in the B band than in R or H band. As has been found in normal spiral galaxies, the spiral arms of UGC 6614 and F568-6 become smoother with increasing wavelength. In our previous work,

Quillen & Pickering 1997, by considering the strength of the spiral structure, we found that the disk of the galaxy had a significant stellar mass compared to the atomic gas component (stellar/gas mass $\gtrsim 1$). Since the disk mass limit depends on strength of the spiral structure, the smoother appearance of the H band images suggests that the disks of these galaxies are somewhat more massive than we estimated in Quillen & Pickering 1997.

The large estimated stellar disk mass in UGC 6614 and F568-6 suggests that a significant gas fraction has been converted into stars. This would be consistent with the near solar metallicities measured by Pickering & Impey 1997 and McGaugh 1994. Since Pickering & Impey 1997 also find that the current level of star formation (based on the number of HII regions detected) is low, if UGC 6614 and F568-6 have a substantial older stellar population as suggested by their red colors and the disk mass limits, then it is likely that these galaxies have undergone a previous epoch of more vigorous star formation. This suggests that the evolutionary history of these two LSBGs is not unsimilar to many nearby normal or high surface brightness spiral galaxies.

The possibility of an older stellar population in UGC 6614 and F568-6 would make these LSBGs quite different than the majority which have blue colors, low metallicities and are suspected to have young stellar populations. As summarized by McGaugh & Bothun 1994, for the majority of LSBGs, despite the “absence of significant star formation, the most plausible scenario is a stellar population with a young mean age stemming from late formation and subsequent slow evolution. These properties suggest that LSBG disks formed from low initial overdensities with correspondingly late collapse times.” We note, however, that with a novel IMF, Padoan et al. 1997 has succeeded in matching the extremely blue colors of some LSBGs with an old (10 Gyr) stellar population. The fact that LSBG galaxies exist with a range of colors (suggesting a variety of evolutionary scenarios) represents a substantial challenge for cosmological galaxy formation studies (e.g. Dalcanton 1997) as

well as in understanding the process of star formation at low surface densities.

A recent CCD based multicolor survey has discovered that 20% of recently identified LSBGs have $B - V > 0.9$ (O’Neil et al. 1997a,b). If these red LSBG galaxies are similar in stellar population to UGC 6614 and F568-6 then they could be galaxies which may have had previous epochs of star formation. One intriguing possibility is that they may have been part of the faint blue galaxy population.

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Fig. 1.— Greyscale B , R and H band images of UGC 6614 and F568-6.

Fig. 2.— B , V , R and H band surface brightnesses and colors as a function of semi-major axis length (or radius from the nucleus) for UGC 6614 and F568-6. In the bottom plots B , V , R and H bands are shown as hexagons, pentagons, squares, and triangles respectively. Note that the ring at $r \sim 40''$ in UGC 6614 is more sharply defined in the blue optical bands. Both galaxies become bluer with increasing radius. Fluctuations in the sky are observed in the H band images at the level of 22.2 mag/''^2 so that points at surface brightnesses fainter than this are unreliable. In B , V and R , fluctuations in the sky (due to errors in the flat fields and reflected light) dominate at $r \gtrsim 70''$ for both galaxies.

Fig. 3.— Comparison of bulge and disk colors in UGC 6614 and F568-6 to those of other galaxies and globular clusters. Colors for UGC 6614 and F568-6 are shown for a range of radius. Since the colors of these two galaxies are so similar only one set of points is shown for both. The reddest colors correspond to the bulge and the bluest colors to the outermost disk (see Fig. 2). Colors have been corrected for galactic extinction (represented by the zero subscript in the axis labels). The colors in UGC 6614 range between colors typical for Sc galaxies to those of SO and Elliptical galaxies. The data for the LMC and SMC globular clusters are from Persson et al. (1983). The data for the E and SO galaxies are from Persson, Frogel & Aaronson (1979). The data for the Sc galaxies are from Frogel (1985). The data for the M31 globular clusters are from Frogel, Persson & Cohen (1980).

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